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NACKA TINGSRÄTT

Mark- och miljödomstolen

Box 1104

131 26 Nacka Strand

SERO:s svar på Föreläggande 2013 05 13 i Mål M 1333-11 angående

SKB: s ansökan om tillstånd till anläggningar i ett sammanhängande system för slutförvaring av använt kärnbränsle och kärnavall.

Komplettering av vårt tidigare svar med Bil. 3 Bränslekollaps i CLAB och

Bil 4: "Man made lava

Till Bil. 4 kan hänvisning göras till att det fortfarande verkar pågå en ytterst svårstoppad härdsmläta i marken under en reaktor i Fukushima.

Materialet presenterat i bil. 4 är till största delen hämtat från

[http://en.wikipedia.org/wiki/Corium_\(nuclear_reactor\)#Corium_composition_and_reactions](http://en.wikipedia.org/wiki/Corium_(nuclear_reactor)#Corium_composition_and_reactions)

<http://www.wired.com/wiredscience/2013/04/the-most-dangerous-manmade-lava-flow>


Olof Karlsson

Projektledare

SERO har tidigare krävt en omedelbar stängning av CLAB i dess nuvarande form och överföra allt bränsle som legat två år i bassäng till torrlager (Bilaga: Dry Cask storage and comparative risks).

SKB beskriver förloppen i CLAB som långsamma. Om kylningen av vattnet i lagringsbassängerna uteblir kommer vattnet att värmas upp. Tiden det skulle ta att värma upp vattnet till kokning och att förånga det är kraftigt beroende av bränslets resteffekt. Om kylningen upphör att fungera vid tidpunkten då bränslet har sin maximala resteffekt tar det i storleksordningen en vecka innan vattnet börjar koka. Lagringsbassängernas utformning och storlek innebär att torrlägningsförloppet är långsamt och det tar ytterligare tio till tolv veckor innan bassängerna är torrlagda. Det finns alltså tid för att fylla på vatten och vidta andra åtgärder.

SERO ifrågasätter SKB:s tolkning av ett händelseförlopp med utebliven kylning mot bakgrund av händelseförloppet i Fukushima. Den stora mängden bränsle i CLAB betyder att ett stort antal zoner med varierande temperatur finns i bränslelagret.

SERO - KOMPLETTERING

Bränslekollaps i CLAB = Kollapsad härd –" Man made lava"

BAKGRUND

Jämförelse med Bränslekollaps i reaktor

Detta är när kärnklyvningen i en kärnreaktor inte längre kyls tillräckligt för att undvika en upphettning av stavarna, inkapsling, reaktorkärl och allt annat i närheten, inklusive betonggolvet i reaktorbyggnaden. När en härds smälta börjar ske, som hände i Tjernobyl 1986 eller Fukushima Dai'ichi år 2011, är det viktiga - förmågan att kyla reaktorn tillräckligt för att hålla bränslestavarna kylda. Följden blir värmen ökar - och ökar snabbt. De två viktigaste primära isotoperna i kärnklyvning är uran - 235 och plutonium - 239, så det är deras fission orsakas av absorption av en neutron till isotoper med ännu kortare halveringstider (som cesium och strontium) är vad som producerar värme i kärnreaktors härd. Den okontrollerade kedjereaktionen av fission, sönderfall och absorption får värmen att öka till den punkt där bränslestavarna (gjorda mestadels av anrikat U, vilket betyder att den har mer 235U än den naturliga fördelningen av 235U) kommer att böja sig, om uppvärmningen tillåts fortsätta och därefter smälta. Detta kontrolleras vanligen av kylvatten och kontrollstavar som kan absorbera en del av de neutroner som skapas genom fission. Men om det finns ett problem, kan värmen fortsätta att stiga och bränslestavarna kan helt smälta, dvs påbörjad "härds smälta". Så, i en mening, är en härds smälta i en kärnreaktor oavsiktlig produktion av lava.

Då bränslepellets inuti bränslestavarna är nästan helt UO₂ medan bränslestavarna i vilka pellets är placerade är gjord av zirkoniumlegeringar. Eftersom värmen från bränslestavarna i en olycka, kan få inkapslingen att börja böja sig (nära 700 °C) och pellets inne i höljet kommer i beröring med höljet, kan de börja smälta om temperaturen når ~1200 °C. Värmen kan fortsätta öka tills bränslestavarna smälter, så småningom bildas en helt smält kropp som är en blandning av UO₂ från bränslepellets och zirkoniumlegeringens hölje. Vid 2000 grader C har smältan lägre viskositet än lava. Det är därför det är så viktigt att veta om en olycka har utvecklats till en "härds smälta" där "lavan" snabbt kommer att smälta sig genom de inre förvaringsbehållare (eller fler) inom några timmar om de inte kan kylas igen. Resultat från

CCI (Core Concrete Interaktion) experiment tyder på att kyla med vatten inte kan vara tillräckligt för att stoppa "lava" från att smälta betongen . En sak att komma ihåg - mycket av smältning av betong under en härdsmlta inträffar inom några minuter till timmar.

Temperaturen på "lavan" kan vara så hög som 2400 °C under de första timmarna efter härdsmltan, potentiellt nå över 2800 °C. En stor mängd värme kan frigöras genom reaktion av metaller (särskilt zirkonium) i "lavan" med vatten . Översvämning av "lava- massan" med vatten, eller droppe av smält "lava" massa i en vattenbassäng, kan resultera i en temperaturspik och produktion av stora mängder vätgas, vilket kan resultera i en tryckspik i reaktorinneslutningen . Den ångexplosion från sådan plötslig "lava" - vattenkontakt kan dispergera de material och projektiler bildas som kan skada inneslutningskärlet genom stöt . Efterföljande tryckstötter kan orsakas av förbränningen av den frigjorda väte . Detonationsriskerna kan minskas genom användning av katalytiska väte- rekombinatorer.

Den smälta reaktorhärden avger flyktiga grundämnen och föreningar. Dessa kan vara i gasfas, såsom molekylär jod eller ädelgaser, eller kondenserade aerosolpartiklar efter att ha lämnat högtemperaturregionen.

SERO kräver:

Redovisning av konsekvenser vid torrläggning enl Nollalternativets 2.4.

Vad är skillnaden mellan en bränslekollaps i CLAB och motsvarande i en reaktor enl redovisat reaktorscenario?

This is when the nuclear fission reaction occurring within a nuclear reactor is no longer cooled and contained sufficiently to prevent heating of the rods, cases, core containment vessel and anything else nearby, including the concrete floor of the reactor building. When a meltdown begins to occur, as what happened at Chernobyl in 1986 or Fukushima Dai'ichi in 2011, the ability to cool the reactor is insufficient to keep the fuel rods cool, so heat begins to build — and build rapidly. The two most important primary isotopes used in nuclear fission reactions are uranium-235 and plutonium-239, so it is their fission caused by the absorption of a neutron into isotopes with even shorter half-lives (like cesium and strontium) are what produces the heat in the nuclear reactor core. The chain reaction of fission, decays and absorption of the released alpha particles by other atoms is allowed to go unfettered, the heat will build to the point where the fuel rods (made mostly of enriched U, meaning it has more ²³⁵U than the natural distribution of ²³⁵U) will start to bend and, if the heating is allowed to continue, melt. This is usually controlled by cooling water and control rods that can absorb some of neutrons created by fission and decay. However, if there is a problem, the heat can continue to rise and the fuel rods can become fully molten, that is the “meltdown”. So, in a sense, a meltdown in a nuclear reactor is the accidental production of lava.

The fuel pellets inside the fuel rods are almost entirely UO₂ while the fuel rods in which the pellets are placed is made of zirconium alloys. As the fuel rods heat in an accident, they can get hot enough to start bending (close to 700°C) and if the pellets inside the casing touch, they can begin to melt if the temperature reaches ~1200°C*. The heat can continue building as the fuel rods melt, eventually forming an entirely molten body that is a mix of the UO₂ from the fuel pellets and the zirconium alloy of the casing.

You can check out some great videos of corium lava flowing like pahoehoe (it has an even lower viscosity, which isn't a surprise as it is at 2000°C, versus 1100-1200°C for your average basalt) or crusting over when they pour water over it. This lab used upwards of 1 ton** of UO₂ lava in some of their experiments to see how quickly corium might melt through the concrete of a nuclear reactor containment vessel (or building). They found that corium lava can melt upwards of 30 cm (12”) of concrete in 1 hour! This is why it is so important to know if a nuclear reactor accident has gone into true “meltdown” as the corium lava will rapidly melt its way through the inner containment vessels (or more) in a matter of hours unless it can be cooled again. However, results from these CCI (core-concrete interaction) experiments, suggest that cooling with water may not be sufficient to stop corium from melting the concrete. One thing to remember — much of the melting of concrete during a meltdown occurs within minutes to hours, so keeping the core cool is vital for stopping the corium from breaching that containment vessel.

Wikipedia

Corium composition and reactions[\[edit source\]](#) | [editbeta](#)

The composition of corium depends on the design-type of the reactor, and specifically on the materials used in the control rods, coolant and reactor vessel structural materials. There are differences between pressurized water reactor (PWR) and boiling water reactor (BWR) coriums.

In contact with water, hot boron carbide from BWR reactor control rods forms first boron oxide and methane, then boric acid. Boron may also continue to contribute to reactions by the boric acid in an emergency coolant.

Zirconium from zircaloy, together with other metals, reacts with water and produces zirconium dioxide and hydrogen. The production of hydrogen is a major danger in reactor accidents. The balance between oxidizing and reducing chemical environments and the proportion of water and hydrogen influences the formation of chemical compounds. Variations in the volatility of core materials influence the ratio of released elements to unreleased elements. For instance, in an inert atmosphere, the silver-indium-cadmium alloy of control rods releases almost only cadmium. In the presence of water, the indium forms volatile indium(I) oxide and indium(I) hydroxide, which can evaporate and form an aerosol of indium(III) oxide. The indium oxidation is inhibited by a hydrogen-rich atmosphere, resulting in lower indium releases. Caesium and iodine from the fission products that can react to produce volatile caesium iodide, which condenses as an aerosol.^[2]

During a meltdown, the temperature of the fuel rods increases and they can deform, in the case of Zircaloy cladding, above 700–900 °C. If the reactor pressure is low, the pressure inside the fuel rods ruptures the control rod cladding. High-pressure conditions push the cladding onto the fuel pellets, promoting formation of uranium dioxide–zirconium eutectic with a melting point of 1200–1400 °C. An exothermic reaction occurs between steam and zirconium, which may produce enough heat to be self-sustaining without the contribution of decay heat from radioactivity. Hydrogen is released in an amount of about 0.5 m³ of hydrogen (at normal temperature/pressure) per kilogram of zircaloy oxidized. Hydrogen embrittlement may also occur in the reactor materials and volatile fission products can be released from damaged fuel rods. Between 1300 and 1500 °C, the silver-cadmium-indium alloy of control rods melts, together with the evaporation of control rod cladding. At 1800 °C, the cladding oxides melt and begin to flow. At 2700–2800 °C the uranium oxide fuel rods melt and the reactor core structure and geometry collapses. This can occur at lower temperatures if a eutectic uranium oxide-zirconium composition is formed. At that point, the corium is virtually free of volatile constituents that are not chemically bound, resulting in correspondingly lower heat production (by about 25%) as the volatile isotopes relocate.^{[1][3]}

The temperature of corium can be as high as 2400 °C in the first hours after the meltdown, potentially reaching over 2800 °C. A high amount of heat can be released by reaction of metals (particularly zirconium) in corium with water. Flooding of the corium mass with water, or the drop of molten corium mass into a water pool, may result in a temperature spike and production of large amounts of hydrogen, which can result in a pressure spike in the containment vessel. The steam explosion resulting from such sudden corium-water contact can disperse the materials and form projectiles that may damage the containment vessel by impact. Subsequent pressure spikes can be caused by combustion of the released hydrogen. Detonation risks can be reduced by the use of catalytic hydrogen recombiners.^[4]

Reactor vessel breaching[\[edit source\]](#) | [editbeta](#)

In the absence of adequate cooling, the materials inside of the reactor vessel overheat and deform as they undergo thermal expansion, and the reactor structure fails once the temperature reaches the melting point of its structural materials. The corium melt then accumulates at the bottom of the reactor vessel. In case of adequate cooling of the corium melt, the melt can solidify and the spread of damage is limited to the reactor itself. However, corium may melt through the reactor vessel and flow out or be ejected as a molten stream by the pressure inside the reactor vessel. The reactor vessel failure may be caused by heating of its vessel-bottom by the corium melt, resulting first in creep failure and then in breach of the

vessel. Cooling water from above the corium layer, in sufficient quantity, may obtain a thermal equilibrium below the metal-creep temperature, without reactor vessel failure.^[5]

If the vessel is sufficiently cooled, a crust between the melt and the reactor wall can form. The layer of molten steel at the top of the oxide may create a zone of increased heat transfer to the reactor wall; this condition, known as "heat knife", exacerbates the probability of formation of a localized weakening of the side of the reactor vessel and subsequent corium leak.^[1]

In case of high pressure inside the reactor vessel, breaching of its bottom may result in high-pressure blowout of the corium mass. In the first phase, only the melt itself is ejected; later a depression may form in the center of the hole and gas is discharged together with the melt with a rapid decrease of pressure inside the reactor vessel; the high temperature of the melt also causes rapid erosion and enlargement of the vessel breach. If the hole is in the center of the bottom, nearly all corium can be ejected. A hole in the side of the vessel may lead to only partial ejection of corium, with a retained portion left inside the reactor vessel.^[6] Melt-through of the reactor vessel may take from a few tens of minutes to several hours.

After breaching the reactor vessel, the conditions in the reactor cavity below the core govern the subsequent production of gases. If water is present, steam and hydrogen are generated; dry concrete results in production of carbon dioxide and smaller amount of steam.^[7]

Corium-concrete interactions[\[edit source\]](#) | [editbeta](#)

Thermal decomposition of concrete produces water vapor and carbon dioxide, which may further react with the metals in the melt, oxidizing the metals, and reducing the gases to hydrogen and carbon monoxide. The decomposition of the concrete and volatilization of its alkali components is an endothermic process. Aerosols released during this phase are primarily based on concrete-originating silicon compounds; otherwise volatile elements, for example, caesium, can be bound in nonvolatile insoluble silicates.^[2]

Several reactions occur between the concrete and the corium melt. Free and chemically-bound water is released from the concrete as steam. Calcium carbonate is decomposed, producing carbon dioxide and calcium oxide. Water and carbon dioxide penetrate the corium mass, exothermically oxidizing the non-oxidized metals present in the corium and producing gaseous hydrogen and carbon monoxide; large amounts of hydrogen can be produced. The calcium oxide, silica, and silicates melt and are mixed into the corium. The oxide phase, in which the nonvolatile fission products are concentrated, can stabilize at temperatures of 1300–1500 °C for a considerable period of time. An eventually-present layer of more dense molten metal, containing fewer radioisotopes (Ru, Tc, Pd, etc., initially composed of molten zircaloy, iron, chromium, nickel, manganese, silver, and other construction materials and metallic fission products and tellurium bound as zirconium telluride) than the oxide layer (which concentrates Sr, Ba, La, Sb, Sn, Nb, Mo, etc. and is initially composed primarily of zirconium dioxide and uranium dioxide, possibly with iron oxide and boron oxides), can form an interface between the oxides and the concrete farther below, slowing down the corium penetration and solidifying within a few hours. The oxide layer produces heat primarily by decay heat, while the principal heat source in the metal layer is exothermic reaction with the water released from the concrete. Decomposition of concrete and volatilization of the alkali metal compounds consumes a substantial amount of heat.^[2]

The fast erosion phase of the concrete basemat lasts for about an hour and progresses into about one meter depth, then slows to several centimeters per hour, and stops completely when the melt cools below the decomposition temperature of concrete (about 1100 °C). Complete melt-through can occur in several days even through several meters of concrete; the corium then penetrates several meters into the underlying soil, spreads around, cools and solidifies.^[3]

During the interaction between corium and concrete, very high temperatures can be achieved. Less volatile aerosols of Ba, Ce, La, Sr, and other fission products are formed during this phase and introduced into the containment building at time when most of early aerosols are already deposited. Tellurium is released with the progress of zirconium telluride decomposition. Bubbles of gas flowing through the melt promote aerosol formation.^[2]

The thermal hydraulics of corium-concrete interactions (CCI, or also MCCI, "molten core-concrete interactions") is sufficiently understood.^[8] However the dynamics of the movement of corium in and outside of the reactor vessel is highly complex, and the number of possible scenarios is wide; slow drip of melt into an underlying water pool can result in complete quenching, while a fast contact of large mass of corium with water may result in a destructive steam explosion. Corium may be completely retained by the reactor vessel, or the reactor floor or some of the instrument penetration holes can be melted through.^[9]

The thermal load of corium on the floor below the reactor vessel can be assessed by a grid of fiber optic sensors embedded in the concrete. Pure silica fibers are needed as they are more resistant to high radiation levels.^[10]

Some reactor building designs, for example, the EPR, incorporate dedicated corium spread areas (Core Catchers), where the melt can deposit without coming in contact with water and without excessive reaction with concrete.^[11] Only later, when a crust is formed on the melt, limited amounts of water can be introduced to cool the mass.^[4]

Materials based on titanium dioxide and neodymium(III) oxide seem to be more resistant to corium than concrete.^[12]

Deposition of corium on the containment vessel inner surface, e.g. by high-pressure ejection from the reactor pressure vessel, can cause containment failure by direct containment heating (DCH).

Specific incidents[\[edit source\]](#) | [editbeta](#)

Three Mile Island accident[\[edit source\]](#) | [editbeta](#)

During the Three Mile Island accident, slow partial meltdown of the reactor core occurred. About 19,000 kg of material melted and relocated in about 2 minutes, approximately 224 minutes after the reactor scram. A pool of corium formed at the bottom of the reactor vessel, but the reactor vessel was not breached.^[13] The layer of solidified corium ranged in thickness from 5 to 45 cm.

Samples were obtained from the reactor. Two masses of corium were found, one within the fuel assembly, one on the lower head of the reactor vessel. The samples were generally dull grey, with some yellow areas.

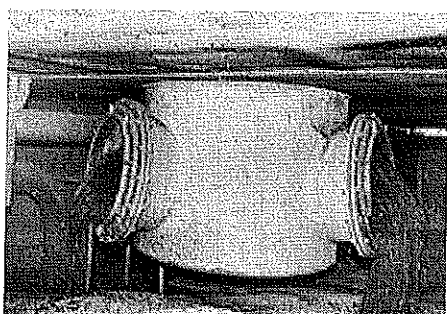
The mass was found to be homogenous, primarily composed of molten fuel and cladding. The elemental constitution was about 70 wt.% uranium, 13.75 wt.% zirconium, 13 wt.% oxygen, with the balance being stainless steel and Inconel incorporated into the melt; the loose debris shown somewhat lower content of uranium (about 65 wt.%) and higher content of structural metals. The decay heat of corium at 224 minutes after scram was estimated to be 0.13 W/g, falling to 0.096 W/g at scram+600 minutes. Noble gases, caesium and iodine were absent, signifying their volatilization from the hot material. The samples were fully oxidized, signifying presence of sufficient amount of steam to oxidize all available zirconium.

Some samples contained a small amount of metallic melt (less than 0.5%), composed of silver and indium (from the control rods). A secondary phase composed of chromium(III) oxide was found in one of the samples. Some metallic inclusions contained silver but not indium, suggesting high enough temperature of volatilization of both cadmium and indium. Almost all metallic components, with exception of silver, were fully oxidized; however even silver was oxidized in some regions. The inclusion of iron and chromium rich regions probably originate from a molten nozzle that did not have enough time to be distributed through the melt.

The bulk density of the samples varied between 7.45 and 9.4 g/cm³ (the densities of UO₂ and ZrO₂ are 10.4 and 5.6 g/cm³). The porosity of samples varied between 5.7% and 32%, averaging at 18±11%. Striated interconnected porosity was found in some samples, suggesting the corium was liquid for sufficient time for formation of bubbles of steam or vaporized structural materials and their transport through the melt. A well-mixed (U,Zr)O₂ solid solution indicates peak temperature of the melt between 2600 and 2850 °C.

The microstructure of the solidified material shows two phases: (U,Zr)O₂ and (Zr,U)O₂. The zirconium-rich phase was found around the pores and on the grain boundaries and contains some iron and chromium in the form of oxides. This phase segregation suggests slow gradual cooling instead of fast quenching, estimated by the phase separation type to be between 3–72 hours.^[14]

Chernobyl accident[[edit source](#) | [editbeta](#)]



 Chernobyl corium lava flows formed by fuel-containing mass in the basement of the plant^[15]

Large amounts of corium were formed during the Chernobyl disaster. The molten mass of reactor core dripped under the reactor vessel and now is solidified in forms of stalactites, stalagmites, and lava flows; the best known formation is the "Elephant's Foot", located under the bottom of the reactor in a Steam Distribution Corridor.^[16]

The corium was formed in three phases.

- The first phase lasted only several seconds, with temperatures locally exceeding 2600 °C, when a zirconium-uranium-oxide melt formed from no more than 30% of the core. Examination of a hot particle shown a formation of Zr-U-O and UO_x -Zr phases; the 0.9 mm thick niobium zircaloy cladding formed successive layers of UO_x , UO_x +Zr, Zr-U-O, metallic Zr(O), and zirconium dioxide. These phases were found individually or together in the hot particles dispersed from the core.^[17]
- The second stage, lasting for six days, was characterized by interaction of the melt with silicate structural materials – sand, concrete, serpentinite. The molten mixture is enriched with silica and silicates.
- The third stage followed, when lamination of the fuel occurred and the melt broke through into the floors below and solidified there.^{[18][19][dead link][20][21]}

The Chernobyl corium is composed from the reactor uranium dioxide fuel, its zircaloy cladding, molten concrete, and decomposed and molten serpentinite packed around the reactor as its thermal insulation. Analysis has shown that the corium was heated to at most 2255 °C, and remained above 1660 °C for at least 4 days.^[22]

The molten corium settled in the bottom of the reactor shaft, forming a layer of graphite debris on its top. Eight days after the meltdown the melt penetrated the lower biological shield and spread on the reactor room floor, releasing radionuclides. Further radioactivity was released when the melt came in contact with water.^[23]

Three different lavas are present in the basement of the reactor building: black, brown and a porous ceramic. They are silicate glasses with inclusions of other materials present within them. The porous lava is brown lava which had dropped into water thus being cooled rapidly.

During radiolysis of the Pressure Suppression Pool water below the Chernobyl reactor, hydrogen peroxide was formed. Hypothesis that the pool water was partially converted to H_2O_2 is confirmed by the identification of the white crystalline minerals studtite and metastudtite in the Chernobyl lavas,^{[24][25]} the only minerals that contain peroxide.^[26]

The coriums consist of a highly heterogeneous silicate glass matrix with inclusions. Distinct phases are present:

- uranium oxides, from the fuel pellets
- uranium oxides with zirconium (UO_x +Zr)
- Zr-U-O
- zirconium dioxide with uranium
- zirconium silicate with up to 10% of uranium as solid solution, $(Zr,U)SiO_4$, called chernobylite
- uranium-containing glass, the glass matrix material itself; mainly a calcium aluminosilicate with small amount of magnesium oxide, sodium oxide, and zirconium dioxide^[27]
- metal, present as solidified layers and as spherical inclusions of Fe-Ni-Cr alloy in the glass phase^[17]

Five types of material can be identified in Chernobyl corium:^[28]

- **Black ceramics**, a glass-like coal-black material with surface pitted with many cavities and pores. Usually located near the places where corium formed. Its two versions contain about 4–5 wt.% and about 7–8 wt.% of uranium.
- **Brown ceramics**, a glass-like brown material usually glossy but also dull. Usually located on a layer of a solidified molten metal. Contains many very small metal spheres. Contains 8–10 wt.% of uranium. Multicolored ceramics contain 6–7% of fuel.^{[29][30]}
- **Slag-like granulated corium**, slag-like irregular gray-magenta to dark-brown glassy granules with crust. Formed by prolonged contact of brown ceramics with water, located in large heaps in both levels of the Pressure Suppression Pool.
- **Pumice**, friable pumice-like gray-brown porous formations formed from molten brown corium foamed with steam when immersed in water. Located in Pressure Suppression Pool in large heaps near the sink openings, where they were carried by water flow as they were light enough to float.^{[31][32][33]}
- **Metal**, molten and solidified. Mostly located in the Steam Distribution Corridor. Also present as small spherical inclusions in all the oxide-based materials above. Does not contain fuel per se, but contains some metallic fission products, e.g. ruthenium-106.

The molten reactor core accumulated in the room 305/2, until it reached the edges of the steam relief valves; then it migrated downward to the Steam Distribution Corridor. It also broke or burned through into the room 304/3.^[30] The corium flowed from the reactor in three streams. Stream 1 was composed of brown lava and molten steel; steel formed a layer on the floor of the Steam Distribution Corridor, on the Level +6, with brown corium on its top. From this area, brown corium flowed through the Steam Distribution Channels into the Pressure Suppression Pools on the Level +3 and Level 0, forming porous and slag-like formations there. Stream 2 was composed of black lava, and entered the other side of the Steam Distribution Corridor. Stream 3, also composed of black lavas, flown to other areas under the reactor. The well-known "Elephant's Foot" structure is composed of two metric tons of black lava,^[17] forming a multilayered structure similar to tree bark. It is said to be melted 2 meters deep into the concrete. As the material was dangerously radioactive and hard and strong, and using remote controlled systems was not possible due to high radiation interfering with electronics,^[34] shots from an AK-47 were used to split off chunks for analysis.^{[35][36][37]}

The Chernobyl melt was a silicate melt which did contain inclusions of Zr/U phases, molten steel and high uranium zirconium silicate ("chernobylite", a black and yellow technogenic mineral^[38]). The lava flow consists of more than one type of material—a brown lava and a porous ceramic material have been found. The uranium to zirconium for different parts of the solid differs a lot, in the brown lava a uranium rich phase with a U:Zr ratio of 19:3 to about 38:10 is found. The uranium poor phase in the brown lava has a U:Zr ratio of about 1:10.^[39] It is possible from the examination of the Zr/U phases to know the thermal history of the mixture, it can be shown that before the explosion that in part of the core the temperature was higher than 2000 °C, while in some areas the temperature was over 2400–2600 °C.

The composition of some of the corium samples is as follows:^[40]

type	SiO ₂	U ₃ O ₈	MgO	Al ₂ O ₃	PbO	Fe ₂ O ₃
slag	60	13	9	12	0	7
glass	70	8	13	12	0.6	5
pumice	61	11	12	7	0	4

Degradation of the lava[[edit source](#) | [editbeta](#)]

The corium undergoes degradation. The *Elephant's Foot*, hard and strong shortly after its formation, is now cracked enough that a glue-treated wad easily separated its top 1–2 centimeter layer. The structure's shape itself is changed as the material slides down and settles. The corium temperature is now just slightly different from ambient, the material is therefore subject to both day-night temperature cycling and weathering by water. The heterogeneous nature of corium and different thermal expansion coefficients of the components causes material deterioration with thermal cycling. Large amounts of residual stresses were introduced during solidification due to the uncontrolled cooling rate. The water, seeping into pores and microcracks and freezing there, the same process that creates potholes on roads, accelerates cracking.^[30]

Corium (and also highly irradiated uranium fuel) has an interesting property: **spontaneous dust generation**, or spontaneous self-sputtering of the surface. The alpha decay of isotopes inside the glassy structure causes Coulomb explosions, degrading the material and releasing submicron particles from its surface.^[41] However the level of radioactivity is such that during one hundred years the self irradiation of the lava (2×10^{16} α decays per gram and 2 to 5×10^3 Gy of β or γ) will fall short of the level of self irradiation which is required to greatly change the properties of glass (10^{18} α decays per gram and 10^8 to 10^9 Gy of β or γ). Also the rate of dissolution of the lava in water is very low (10^{-7} g·cm⁻² day⁻¹) suggesting that the lava is unlikely to dissolve in water.^[42]

It is unclear how long the ceramic form will retard the release of radioactivity. From 1997 to 2002 a series of papers were published which suggested that the self irradiation of the lava would convert all 1,200 tons into a submicrometre and mobile powder within a few weeks.^[43] But it has been reported that it is likely that the degradation of the lava is to be a slow and gradual process rather than a sudden rapid process.^[42] The same paper states that the loss of uranium from the wrecked reactor is only 10 kg (22 lb) per year. This low rate of uranium leaching suggests that the lava is resisting its environment. The paper also states that when the shelter is improved, the leaching rate of the lava will decrease.

Some of the surfaces of the lava flows have started to show new uranium minerals such as $\text{UO}_3 \cdot 2\text{H}_2\text{O}$ (eliantinite), $(\text{UO}_2)\text{O}_2 \cdot 4\text{H}_2\text{O}$ (studtite), uranyl carbonate (rutherfordine), and two unnamed compounds Na

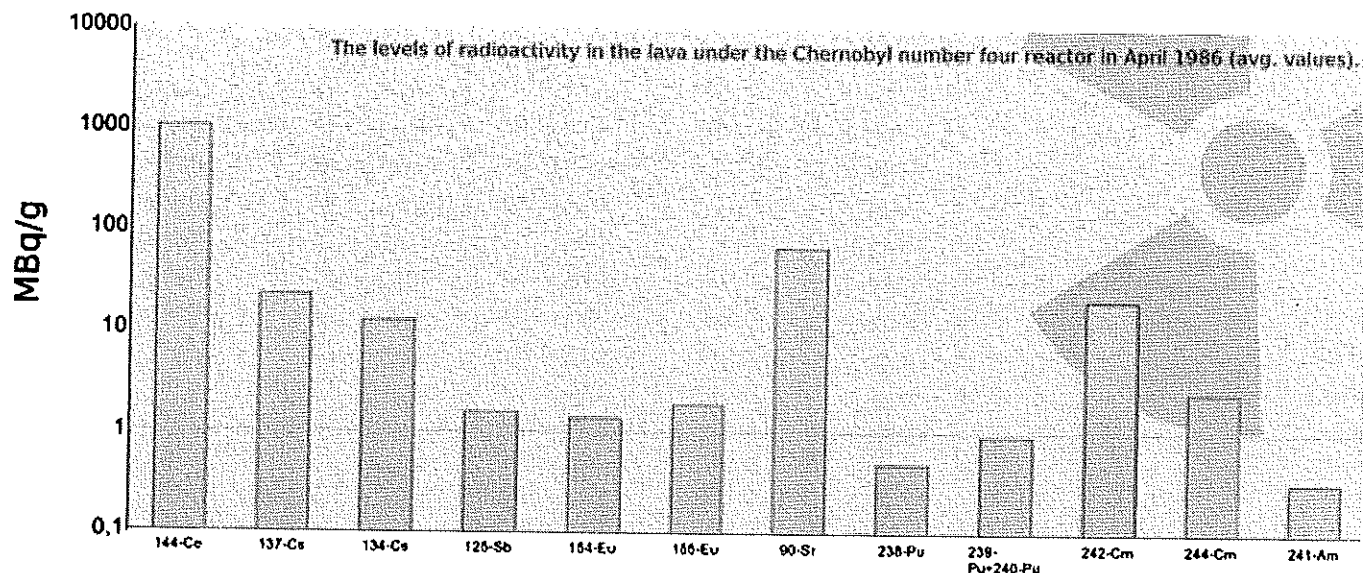
$4(\text{UO}$

$2)(\text{CO}$

$3)$

3 and $\text{Na}_3\text{U}(\text{CO}_3)_2 \cdot 2\text{H}_2\text{O}$.^[30] These are soluble in water, allowing mobilization and transport of uranium.^[44] They look like whitish yellow patches on the surface of the solidified corium.^[45] These secondary minerals show several hundred times lower concentration of plutonium and several times higher concentration of uranium than the lava itself.^[30]

It is possible to see in the photo shown below that the corium (molten core) will cool and change to a solid with time. It is thought that the solid is weathering with time. The solid can be described as *Fuel Containing Mass*, it is a mixture of sand, zirconium and uranium dioxide which had been heated at a very high temperature^[46] until it has melted. The chemical nature of this *FCM* has been the subject of some research.^[47] The amount of fuel left in this form within the plant has been considered.^[48] A silicone polymer has been used to fix the contamination.



Source: http://www.kiae.ru/rus/inf/chnpp/pr_fcm.htm



The radioactivity levels of different isotopes in April 1986, in the FCM

Fukushima Dai-ichi[[edit source](#) | [editbeta](#)]

At an estimated eighty minutes after the March 11, 2011 [tsunami strike](#) (which caused various [nuclear accidents](#), the worst of which being the [Fukushima Daiichi nuclear disaster](#)), the temperatures inside Unit 1 of the [Fukushima Daiichi Nuclear Power Plant](#) reached 2300 °C to 2500 °C, causing the fuel assembly structures, control rods and nuclear fuel to melt and form corium. The reactor core isolation cooling system (RCIC) was successfully activated for Unit 3, however the Unit 3 RCIC subsequently failed and at about 09:00 on March 13 the nuclear fuel had melted into corium. Unit 2 retained RCIC functions slightly longer and corium is not believed to have started to pool on the reactor floor until around 18:00 on March 14 ^[49]

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